SEARCH FOR ^{26}AL EMISSION IN THE VELA REGION WITH INTEGRAL/SPI

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ABSTRACT

The study of nucleosynthesis in our Galaxy is one of the main scientific goals of the INTEGRAL mission. We focus here on the 1809 keV γ-ray line produced by radioactive decay of ^{26}Al. The first map of the ^{26}Al emission along the plane of the Galaxy from COMPTEL had revealed surprisingly-bright emission in the Vela region. This is of special interest, because in this region candidate ^{26}Al source objects may be as close as 200 pc, and thus could be detected as individual sources, in contrast to the diffuse glow from superimposed sources in most other regions. In 2003, INTEGRAL observed the Vela region during time spans in June-July and Nov-Dec for a total of ~ 2.5 Ms. We report first analysis efforts from an on-off technique, and elaborate on the issues of precise energy calibration and background tracing, which proved essential due to solar flare activation events during our observations. No detection of ^{26}Al emission can be reported yet.

Key words: SPI; ^{26}Al-1809 keV; Vela region.

1. INTRODUCTION

Precise measurements of γ-ray line intensities (Vedrenne et al., 2003), line profiles and Doppler shifts are among SPI's primary goals (Schönfelder, 1999). The Vela region is one of the few observable regions in our Galaxy where the individual sources which could contribute to the extended emission of ^{26}Al can potentially be disentangled by INTEGRAL for a cross-check with nucleosynthesis models of these sources. With its half-life of 0.7 Myr, an ^{26}Al nucleus has enough time to escape its optically thick production site, located inside astrophysical sources such as supernovae and Wolf-Rayet (WR) stars, to reach the ISM before it decays to an excited state of the ^{26}Mg nucleus, which deexcites through the emission of a 1809 keV photon. In this respect, the discovery of this emission (measured flux of $(3.6\pm1.2)\times10^{-5}$ ph
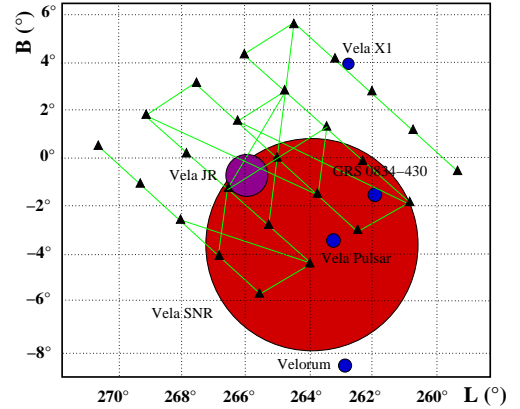

Figure 1. Schematic view of the Vela region: ^{26}Al is expected from Vela SNR, Vela Jr and the Wolf-Rayet star γVelorum. The observations during the first campaign (June/July 2003) are shown as full triangles. The dithering pattern (5 × 5) is visible.

cm^{-2} s^{-1}) in the Vela region by COMPTEL (Diehl et al., 1995, 1999) was a major advance in the field of nuclear astrophysics. However, COMPTEL did not have enough angular resolution to determine the sources of this emission and did not have enough spectral resolution to study their physics.

Figure 1 presents a schematic view of the Vela region in galactic coordinates. As emphasized above, several potential sources of ^{26}Al can be found in this region: the supernova remnant Vela SNR ($d = 250 \pm 30$ pc, age ~ 11 kyr, Cha et al., 1999), the very young core collapse SNR GRO J0852-46 (for Vela Junior, age and distance are very incertain and an upper limit is set by combining the ROSAT and COMPTEL data: $d < 500$ pc, age < 1.1 kyr, Aschenbach et al., 1999), and the WR star γVelorum ($d = 258^{+41}_{-31}$ pc, van der Hucht et al., 1997) which could be also a potential source (non-detection by COMPTEL, see also Mowlavi et al., these proceedings). In an alternative scenario, massive stars associations could be responsible for most of the 1.809 MeV flux (Lavraud et al., 2001).
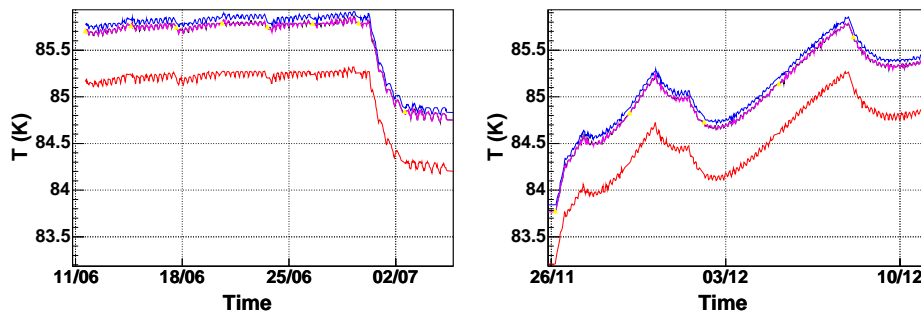
Figure 2. Cold plate temperature (4 sensors) during rev. 81-88 (left panel) and rev. 137-141 (right panel).

We superimposed on Fig. 1 the attitude (pointings and trajectories between successive pointings) of the satellite following a 5×5 dithering pattern. This figure corresponds to the first campaign of Vela observation, providing 1.2 Ms (exposure time) of data as a part of the 2003 Core Program (11 June to 05 July, i.e. satellite revolution 81 to 88). The second set of data follows a similar dithering pattern, displaced toward γVel; the observation took place from 27 November to 12 December i.e. revolution 137 to 141. Notice that during rev. 140 (6 December 2003), one of the detectors count rate dropped to zero (18 active detectors left); the detector failure is under investigation. This has potentially an influence on i) the energy redistribution response of the γ-camera, ii) the background distribution in single detector events and iii) the deconvolution algorithm. In this preliminary study, we do not use the properties of the coded aperture, but instead we use the on-off method where only the count rates of the detectors are required. The 'on' signal corresponds to the Vela observations (signal+background) and the 'off', to an empty field which is supposed to be only background.

2. ANALYSIS

The search for the astrophysical 1.809 MeV deexcitation line in the data is very difficult due to the strong background lines of similar energy. The first step towards a clear identification of the signal is the energy calibration of the data. A drift in the energy calibration is sufficient to blur any potential signal. However, the main difficulty is the background. The radiation environment is responsible for its temporal evolution, and the variability has to be modeled to better than 1% to reveal a signal (see Knödlseder et al. for a more complete study in the case of the Cygnus region, these proceedings).

2.1. Energy calibration

The temporal evolution of the energy calibration can be monitored via the cold plate temperature of the Ge-camera. More precisely, the energy calibration function $E(\text{keV}) = f(\text{ADCbin})$ depends implicitly
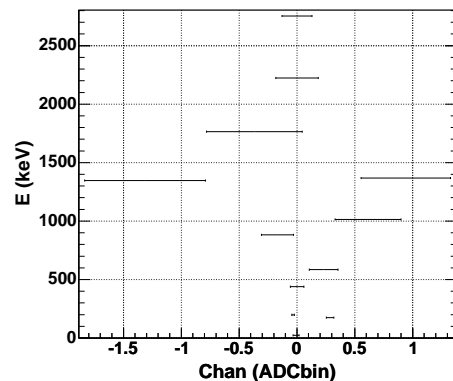

Figure 3. Residue of the difference between the true position of several calibrations lines and the fitted value for these same peaks (detector 0, rev. 81). See text for further comments.

on the temperature T of the Ge-detector (see Lonjou et al., these proceedings). This temperature is measured by 4 sensors located in the Ge-camera cold box. The energy calibration is almost linear, following the relation 1 ADCbin $\sim$ 0.135 keV for the low energy ADCbin range. A drift of 1 K corresponds to an energy shift of $\sim$ 0.13 keV (Roques et al., 2003). As can be seen in Fig. 2, strong temperature variations are measured for revolution 87 and 137-141. We wish to inspect here more clearly the impact of the temperature drift for the Vela data.

Unlike the standard procedure implemented at ISDC, we calibrate the low energy ADCbin range (below 2 MeV) using a combined fit of two quadratic functions: one for an energy below $\sim$ 220 keV and one above (with continuity of the function and its derivative enforced). We found that, for the same sample of background lines, this kind of function fits slightly better (in the low energy range) the background peaks measured (using a gaussian fit) by the instrument, compared to the standard fit using $E = a_0/C + a_1 + a_2 C + a_3 C^2$. Figure 3 illustrates the quality of our fit for the case of the detector 0. We fit our function on 10 background lines below 2 MeV using all data of one revolution (72 h). We then display for each line the residue, i.e. the difference between the value given by our fit function to the position of the peak observed in the detector. At low energy
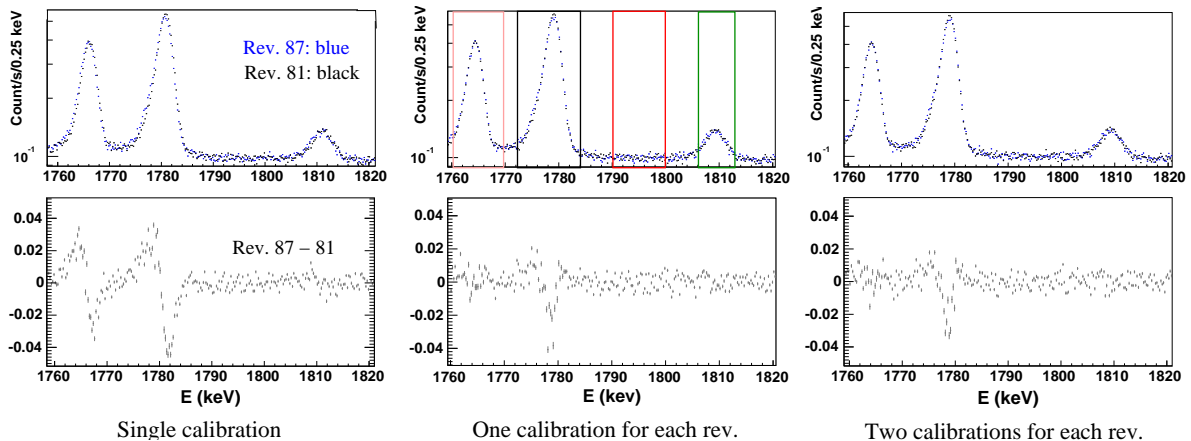
Figure 4. On-Off as a check of the calibration quality illustrated with rev. 87 - rev. 81. The balance between a good calibration and statistical limitations is obtained with one (middle) or two (right) calibrations by revolution. The four colored bands in the upper central figure tag three background lines and continuum used in Fig. 5.

(below 1 MeV), the fit is better than 0.05 keV; the two highest energy points show no residue since these points correspond to the high energy ADCbin range (above 2 MeV) where only two background lines are used (linear fit). The operation is repeated for each Germanium detector (the same kind of residues are obtained).

Inspecting the general trend of these residues (as displayed in Fig. 3) in all detectors and for various revolutions, leads to several remarks concerning the low energy ADCbin range fit. The 1368.6 and 1764.4 keV lines are systematically lower than the fitted value (negative residue) whereas the 1014.4 and 1347.1 keV lines are always higher (positive residue). It is important to remind that the fit function contains no physics. It is only an attempt to find a function which provides a continuous and smooth description of the ADCbin to keV conversion on the whole energy range for all known background lines in the selection. A failure to reproduce the physical peaks measured in the detector only means that the real energy of the corresponding lines are estimated incorrectly. This is the case when the lines are blended or form a complex (as it is the case for most background lines, Weidenspointner et al., 2003) with each component varying with time; it is also the case when the low energy tail of the line is replenished (degradation of the camera resolution due to Ge crystal defects created by cosmic radiation), shifting the position of the peak toward lower energy. It is finally the case if the statistics is simply too limited, implying an inaccurate determination of the energy peak position. There is an obvious trade-off between temporal drifts and statistical accuracy for choosing the sampling interval. Whereas at low energy, a very good calibration can be achieved and sub-revolution calibrations can confidently be implemented, in the 1809 keV region, it is difficult to obtain a statistical accuracy better than 0.15 keV even with one full orbit of data.

Once the fit is performed, one can produce calibrated data using different sampling periods and then use these data to find the best compromise with the statistics. Strong instrumental background lines (see Fig. 4, upper panels) are located around 1.8 MeV (Weidenspointner et al., 2003): ^{205}Bi and ^{214}Bi lines (1764 keV); blend of ^{205}Bi (1776 keV) and ^{28}Al lines (1779 keV); blend of unknown lines (1805.8 keV), ^{26}Na (1808.7 keV) and ^{56}Mn (1810.9 keV). Subtracting rev. 81 (which has a stable temperature) to rev. 87 (for which temperature changes rapidly during the orbit, see Fig. 2) reveals more clearly what is the best sampling period. The lower panel in Fig. 4 shows this difference for the single events (see Schanne et al., 2003 for details about single SE and multiple ME events): the left panel uses the same calibration function for revolution 87 and 81; the middle panel uses a calibration sampling interval of one orbit; the right panel uses two energy calibrations per orbit. The gain obtained using a sampling interval of one orbit is seen compared to a single calibration for long periods. More frequent calibrations have noticeable effects at low energy (not shown here), because the temperature drift is large in the Vela data. However, as mentioned above, at high energy the statistics becomes quickly limited, and one cannot go beyond two calibrations per orbit (see right panel). Hence, the above method cannot be applied on shorter sampling periods. The only way to overcome this limitation is to have a deterministic calibration model depending explicitly on the temperature and on the time elapsed since last annealing (see Lonjou et al., these proceedings). This provides a relative calibration and the comparison of background line positions between SE and reconstructed ME eventually checks the absolute calibration accuracy. Note that the intrinsic dependence on time due to the detector degradration is always negligible within one orbit (Fig. 5 in Lonjou et al.).

2.2. Background evolution

During each of the two data taking periods (June and December 2003), strong solar flares occurred. The upper panel of Fig. 5 shows the temporal evolution
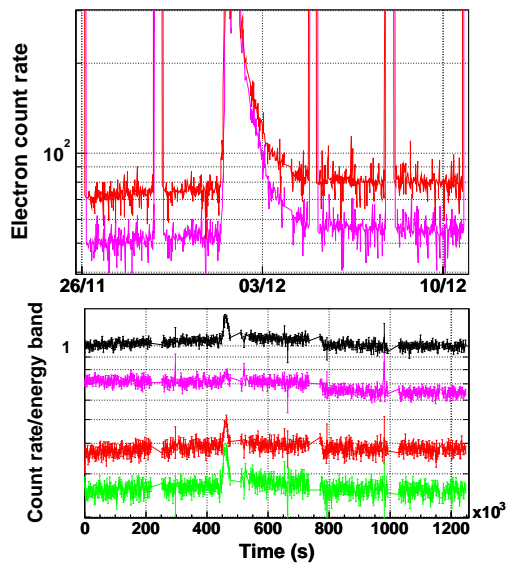
Figure 6. All Vela data (SE+ME) - empty field (from rev. 75) using two energy calibrations for revolutions with large temperature drift (see text).

137-141) and subtracting an empty field (taken during rev. 75) is presented in Fig. 6 (Single Events + Multiple Events). No positive detection is obtained. However, the major shortcomings of this preliminary study are that i) no background model has been used and ii) the long exposure time accumulated in the Vela region is limited by the short duration of the off-field (corresponding to $\sim$ 200 ks).

3. CONCLUSIONS

A preliminary study of the 1.8 MeV γ-ray line was performed in the Vela region, using all observations available ($\sim$2.5 Ms). A simple on-off technique was used and no astrophysical ^{26}Al signal was found, but this crude analysis needs to be refined in several ways. Whereas a satisfactory energy calibration was used, the resolution degradation with time has not been addressed; it should be taken into account properly since the two data taking periods (as well as the off observations) did not take place at the same period after an annealing of the defects in the Ge detectors. Actually, the most important point, in order to be able to put limits on a signal, is to implement the background model developed by the SPI collaboration.

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Figure 5. Upper panel: IREM count rate (red E = 0.55 to 2.3 MeV, purple E > 0.5 MeV). The radiation belts are visible for each revolution, and the solar flare occurs at the beginning of rev. 139. Lower panel: Temporal evolution of the four energy regions also shown in Fig. 4.

of the low energy electron count rates (lower curve: E = 0.55 to 2.3 MeV, upper curve: E > 0.5 MeV) measured by the INTEGRAL/IREM (Hajdas et al., 2003) during the second campaign (December). In the first one, a similar but weaker event was observed during rev. 83 (June). The overall SPI/ACS count rate (not displayed here) also shows a strong enhancement due to the solar particles, not seen in the saturated count rates of the ACS. On the other hand, after the flare, the Ge-camera events above 8 MeV are diminished, showing a reduction of the Galactic Cosmic-Ray intensity (Forbush effect). In the lower panel of Fig. 5, integrated count rates in four bands (as shown in Fig. 4) are displayed (white 1760-1768, black 1772-1784, red 1790-1800, green 1806-1812 keV). In particular the rapid evolution of the background during the December solar flare is visible. The enhancement is different depending on the energy band. For example, the 1764 keV line does not vary much. This is expected because this line comes partly from the decay of ^{214}Bi which belongs to the ^{238}U series (natural radioactivity). More generally, even in a quiet period, unstable isotopes build-up in the detector and the general variation on the 1.8 MeV background complex has to be monitored (see Jean et al., 2003). Such background models are mandatory in order to reach the sensitivity which permits to detect the astrophysical 1.8 MeV signal. This is work in progress.

2.3. Result

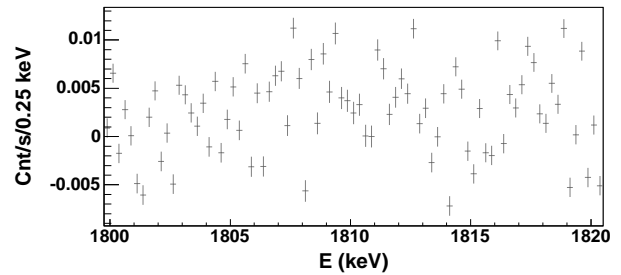The result obtained summing all Vela observations (using two calibrations per revolution for rev. 87 and